Multicast Routing and Wavelength Assignment in WDM Mesh Networks with Sparse Splitting

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***Abstract*—In this paper routing and wavelength assignment for supporting multicast traffic is investigated in WDM mesh networks under sparse splitting constrain. This problem is generally solved in two phases respectively with the purpose of minimizing the number of wavelengths required. Alternative routing is first proposed to route each session by pre-computing a set of candidate light-forests. Then wavelength assignment is formulated as a coloring problem by constructing a conflict graph. Potential heuristic algorithms are proposed.**

***Index Terms*—WDM Networks, Multicast, Routing and Wavelength Assignment (RWA), Sparse Splitting,**

I. Introduction

Optical wavelength division multiplexing (WDM) networking has been identified as an effective technique for future wide area network environments, due to its potential ability to meet rising demands of high bandwidth and low latency communications [1]. For bandwidth-driven and time sensitive applications such as video-conference, shared workspace, distributed interactive simulation and software upgrading in WDM networks, multicasting is advised. The purpose of multicast routing is to provide efficient communication services for applications that necessitate the simultaneous transmission of information from one source to multiple destinations. To support multicast in WDM networks, the network nodes should be equipped with light splitters, which is capable of splitting the incoming light signal into all the outgoing ports. However, in sparse splitting WDM networks, only a fraction of nodes are capable of splitting (named multicast capable nodes, i.e. MC) while the rest only have TaC (Tap and Continue) capacity (called MI nodes), which is able to tap into the light signal for local consumption and forward it to only one output port. Besides, the wavelength converters are not available because of the expensive fabrication.

II. Multicast Routing and Wavelength Assignment in WDM Mesh Networks

Multicast routing and wavelength assignment in WDM networks is a challenging work. This problem can be generally formulated as follows: given the number of wavelengths $|W|$ supported per fiber link, try to establish as many multicast demands as possible. In other words, it is to minimize the number of wavelengths required per fiber so that a set of concurrent multicast demands $Traffic = \{ms_i(s_i, D_i)|i \in [1, I]\}$ could be accommodated. Generally this problem is either decomposed into two subproblems with each one resolved separately by heuristic algorithms, or formulated as an Integer Linear Programming (ILP) and solved once entirely. ILP works well when the topology is small and the group size is not big. Nervelessness, heuristic algorithm is more time efficient while giving an efficient approximated result. Considering the time efficiency, we prefer to separate the multicast routing and wavelength assignment problem into two phases. The first phase is multicast routing, which tries to find the light-forest for routing the multicast demand. After this phase, the wavelength assignment operation for the computed light-trees is performed. This subproblem aims to minimize the number of wavelengths required by the multicast sessions while respecting the WDM layer impairments.

A. Multicast Routing with Sparse Splitting

In full splitting WDM networks, where all nodes are capable of light splitting, one light-tree (LT) is sufficient to span all the multicast members and thus it is able to establish the multicast session. As proved in [2], it is a Steiner problem and NP-hard to find the light-tree with the optimal fiber link cost. In spare splitting WDM networks [3], only a fraction of nodes are MC nodes while the rest are MI nodes. In this case, the out degree of a node in the light-tree is restricted according to its splitting capacity. Thus, one light-tree [4] may not be able to cover all the members, and several ones rooted at the same source are required, i.e. light-forest [3]). And the latest research shows that a set of light-hierarchies can be a better candidate for sparse splitting multicast routing [5].

However, in order to achieve the global objective, the alternative routing should be employed instead of the traditional fixed routing. This is to say, for each multicast session $ms_i(s_i, D_i)$, a set of candidate light-forests (LF) $\{LF_{i1}, LF_{i2}, ..., LF_{iJ}\}$ are pre-computed, only one of which will be employed when routing the multicast session. Hence, the key operation of this subproblem is how to choose a set of light-forests for the same multicast session. Potential methods for computing candidate J light-forests are listed below.

- Choosing the J light-forests as link disjoint as possible.

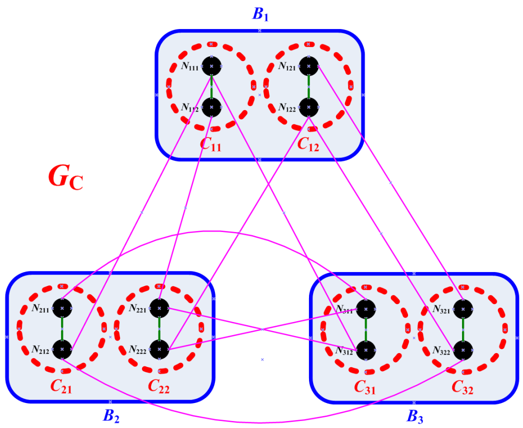

Fig. 1. An example auxiliary graph G_c

- Choosing the J light-forests which require as few wavelength as possible.
- Choosing the J light-forests which consume as little cost as possible.

B. Wavelength Assignment for Multicast Communications

After finishing the routing stage, wavelengths should be assigned for each light-forest. Due to the absence of wavelength converters, wavelength continuity constraint and distinct wavelength constraint should be respected. Hence, any pair of light-trees can be assigned the same wavelength if and only if they are link disjoint. Obviously, the light-trees of the same light-forest should use distinct wavelengths, because they always share some common links. Based on this constraint, an auxiliary conflict graph $G_C$can be constructed to help to resolve the wavelength assignment problem. The auxiliary graph is built following the rules below.

- Each multicast session $ms_i(s_i, D_i)$ is represented by a block B_i, $1 \leq i \leq I$.
- In B_i, each candidate light-forest LF_{ij} pre-computed for $ms_i(s_i, D_i)$ is denoted by a circle C_{ij}, $1 \leq j \leq J$.
- Each light-tree in a light-forest C_{ij} is replaced by a node N_{ijk}.
- In each circle $C_{i,j}$, draw a conflict line between each pair of nodes.
- For any pair of light-trees in different blocks, says N_{1jk} in B_1 and N_{2jk} in B_2 respectively, draw a conflict line between them if they share a common link.

With the help of the built auxiliary graph, the RWA problem is translated into a coloring problem, which tries to minimize the number of colors in G_c so that one and only one circle C_{ij} is selected for each block B_i and adjacent nodes should be colored differently. An example auxiliary graph is is shown in Fig 1. Three multicast sessions are considered. For each session, two candidate light-forests are pre-computed. And each light-forest contains two light-trees. i.e. $I = 3, J = 2, K = 2$.

We can see that when full splitting is adopted in WDM networks, $J = 1$ and $K = 1$, i.e., only one light-forest is pre-computed for a multicast session, and there is only one light-tree in each light-forest. In this case, the wavelength assignment problem is equivalent the traditional coloring problem, which is proven NP-complete. However, under sparse slitting constraint, this problem becomes even harder. Therefore, heuristic algorithm should be developed. One possible method is described as following.

- Calculate the out degree (the number of connection lines to the other circles) for all the the circle C_{ij} in the graph G_c.
- In each block B_i, select the C_{ij} with the smallest out degree, and remove the rest together with the connection lines from G_c.
- In the modified graph, say G_c', the wavelength assignment problem is translated to the traditional coloring problem.
- Next, use some well-known standard coloring heuristics to solve the problem. For instance, degree Largest-First, degree Smallest-First, Color-Degree [6], and Tabu search algorithms [7] .

III. Conclusion

The problem of routing and wavelength assignment for a set of multicast demands is studied in this paper. The objective is to minimize the session blocking probability or minimize the number of wavelengths needed per fiber link. We divide this problem into two subproblems and solve them separately. To route the multicast sessions, alternative routing method is employed, which pre-computes a set of candidate light-forests for each session. Then, the wavelength assignment for the light-forests is translated into to a coloring problem by constructing an auxiliary conflict graph. By combing these two steps, the multicast routing and wavelength assignment problem can be solved. In the future work, simulation will be done to assess and verify the proposed methods.

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